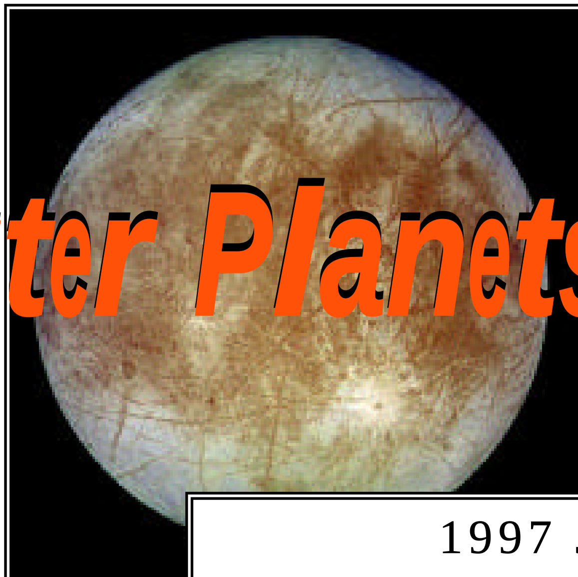
JPL

NASA

Ice & Fire Preprojects

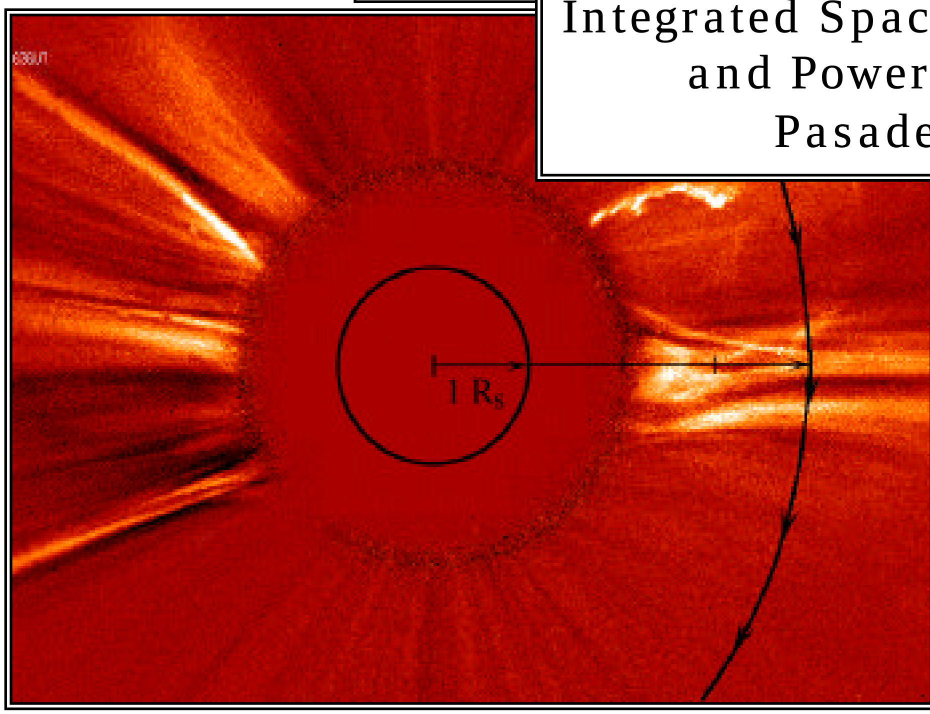
# Outer Planets Exploration



1997 June 3

Integrated Space Microsystems and Power Workshop

Pasadena, CA





Robert L. Staehle
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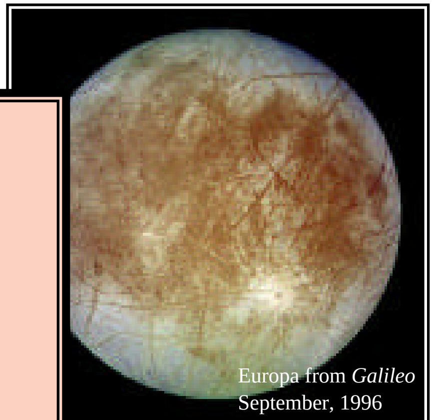
# OUTER PLANETS EXPLORATION PROGRAM

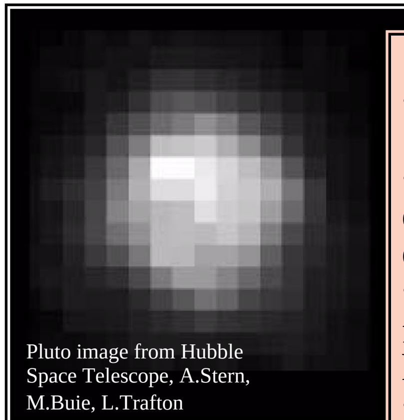
... high-yield science at the most difficult destinations

## Europa Orbiter

- Confirm & characterize possible subsurface ocean.
- Focus the search for possible biologically-relevant discoveries.
- *Extreme propulsion and radiation demands.*
- *Exacting measurements to build on* Galileo *results.*



Europa from *Galileo* September, 1996



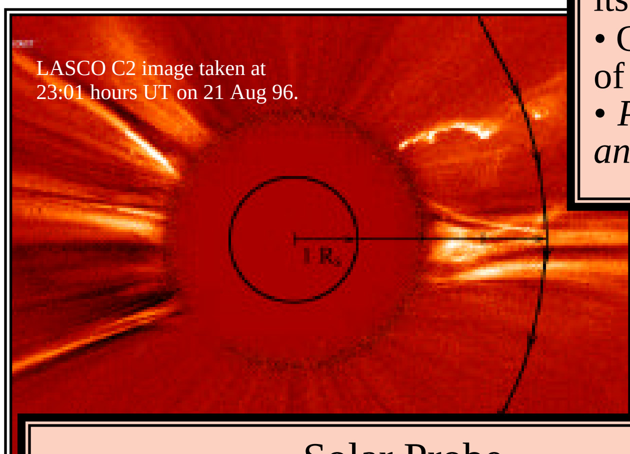
Pluto image from Hubble Space Telescope, A.Stern, M.Buie, L.Trafton

## Pluto-Kuiper Express

- Complete our reconnaissance of the Sun's planets.
- Characterize Pluto/Charon, expect >= 1 Kuiper Disk Object encounter.
- Survey remnant bodies in region from which Earth's volatiles may have come.
- *Extreme distance and long lifetime.*
- *Pluto headed away from Sun.*

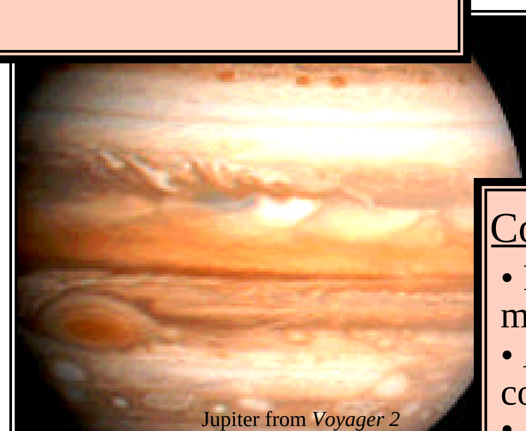
## Jupiter Deep Probes

- Explore the nature and dynamics of Jupiter's atmosphere to depths where its fundamental composition is represented.
- Characterize Jupiter as a key representative of planets being detected around other stars.
- *Probing to extreme temperatures and pressures.*



LASCO C2 image taken at 23:01 hours UT on 21 Aug 96.

Comet Hale-Bopp 97/03/21, J.Young, JPL



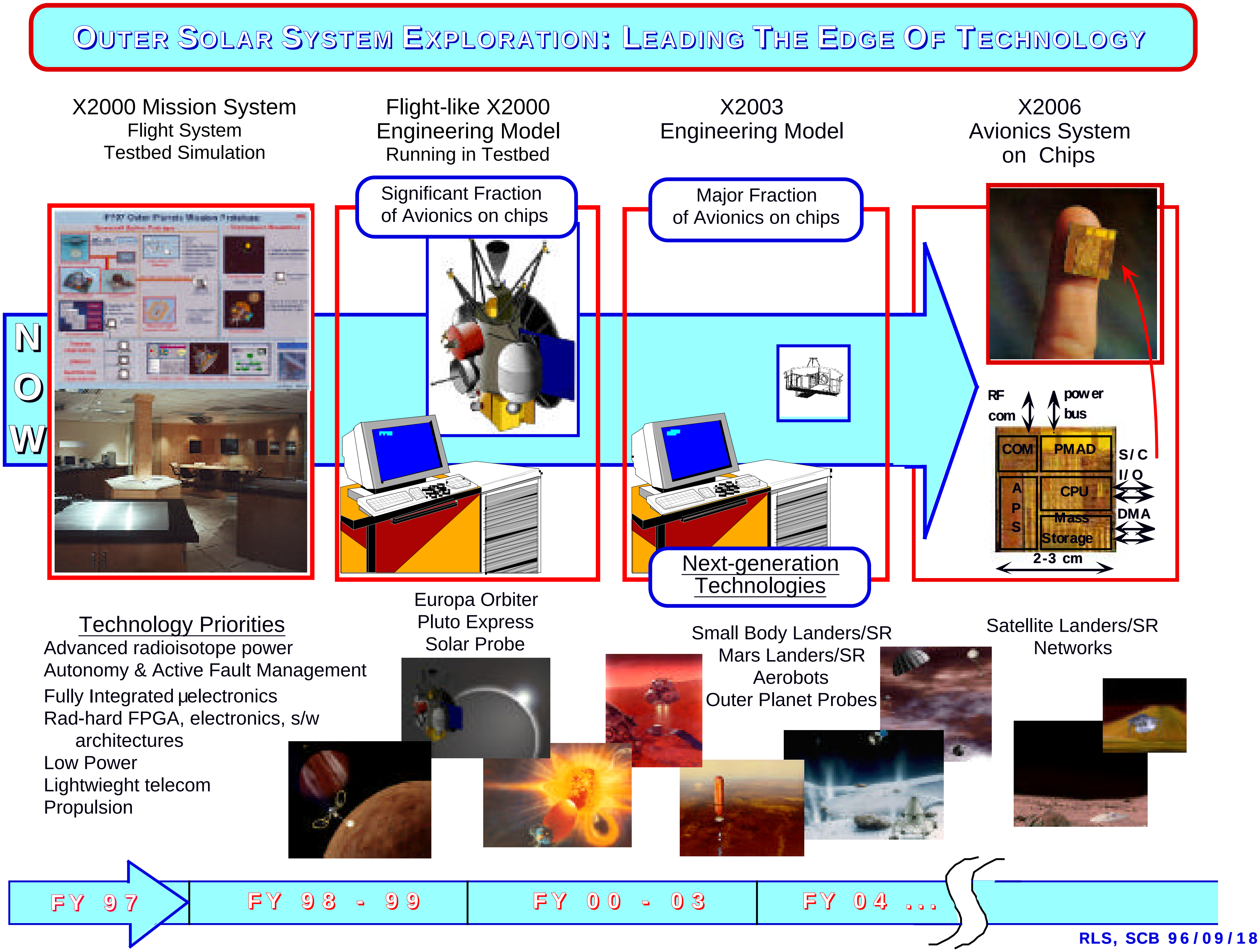
Jupiter from *Voyager 2*

## Solar Probe

- Explore the source of the Sun-Earth connection.
- Origin of Solar Wind and Coronal heating.
- *Extreme heat, thermal range, and challenging measurements near Sun.*

## Comet Nucleus Sample Return

- Return pristine comet nucleus material to Earth.
- Acquire detailed *in situ* sample context measurements.
- *Sampling system, sensors, autonomy, solar-electric propulsion.*


OUTER SOLAR SYSTEM EXPLORATION: LEADING THE EDGE OF TECHNOLOGY
X2000 Mission System
Flight System
Testbed Simulation
Flight-like X2000
Engineering Model
Running in Testbed
X2003
Engineering Model
X2006
Avionics System
on Chips
Significant Fraction
of Avionics on chips
Major Fraction
of Avionics on chips
NOW
RF
com
power
bus
COM
PMAD
S/C
I/O
A
P
S
CPU
Mass
Storage
DMA
2-3 cm
Next-generation
Technologies
Technology Priorities
Advanced radioisotope power
Autonomy & Active Fault Management
Fully Integrated μelectronics
Rad-hard FPGA, electronics, s/w
architectures
Low Power
Lightwieght telecom
Propulsion
Europa Orbiter
Pluto Express
Solar Probe
Small Body Landers/SR
Mars Landers/SR
Aerobots
Outer Planet Probes
Satellite Landers/SR
Networks
FY 97
FY 98 - 99
FY 00 - 03
FY 04 ...
RLS, SCB 96/09/18

## EUROPA MISSION SCIENCE OBJECTIVES (Draft)

• Characterize the surface processes (geology and geomorpholog

• Determine the extent of and depth to liquid water

• Determine the energy sources and response of the crust

## MEASUREMENT OBJECTIVES (Draft)

• Map the entire surface at 100 meter/line-pair resolution in seve colors

• Measure the depth of the ice crust by active radar sounding

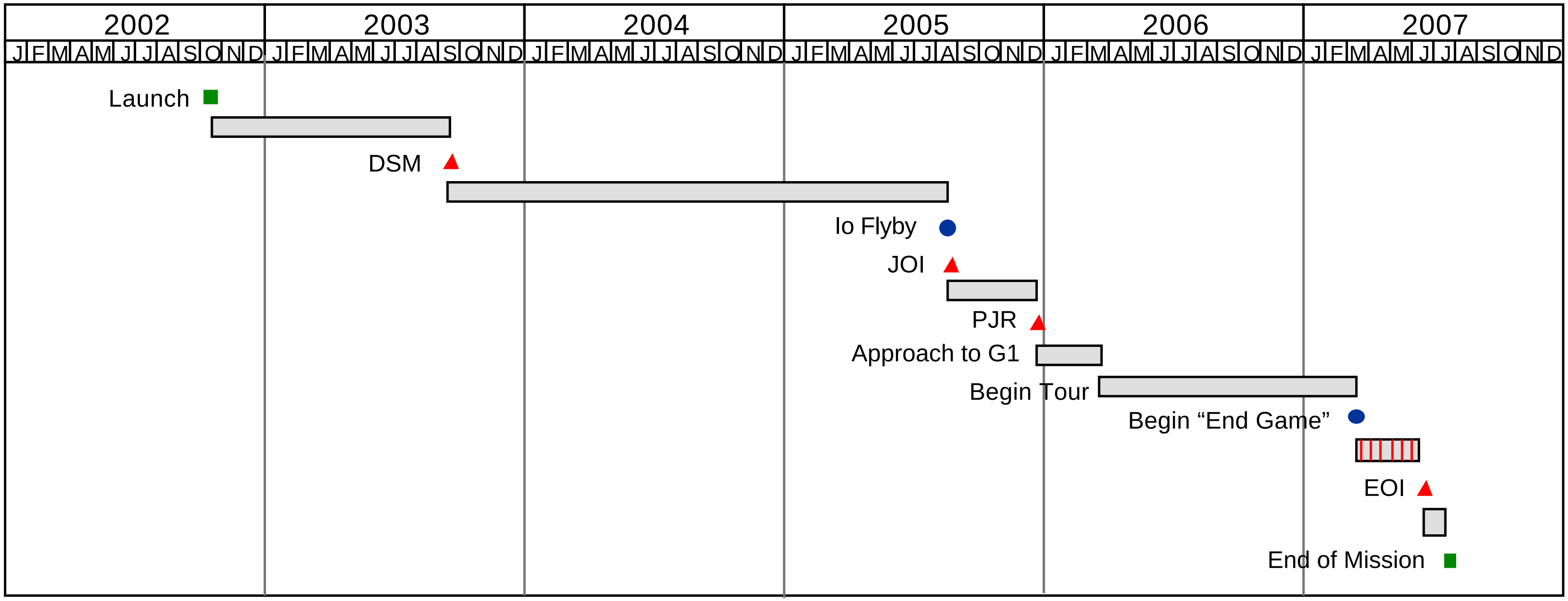
• Characterize the tidal response of the surface by altimetry ( ~ 1 meter altitude resolution) and geodesy

# Europa Mission Considerations

- Radiation environment
  - We think 4 MRad environment can be survived with X2000 Bus
    - Rad hard parts, where cost effective
    - Radiation tolerant system design, including self-shielding enclosure
    - minimum volume microelectronics with heavy shielding enclosure
- Power
  - Europa radar mission requires ~150 $W_E$
  - 3 brick Radioisotope Power Source (RPS) would meet Europa rqmts. and provide needed Pluto power margins.
- Propulsion
  - Biprop module required for Europa
  - Hydrazine thrusters needed for RCS and reaction wheel unloading
- Avionics and Telecom
  - X2000 3D stack avionics and telecom should meet Europa, Pluto, and Solar Probe needs with a common, flexible, and upgradeable architecture and design.

# Europa Orbiter Event Timeline
# (DRAFT)

Direct Option




| **Event** | **Date** |
|---|---|
| Launch | 11-Oct-02 |
| DSM | 07-Sep-03 |
| Io Flyby | 28-Aug-05 |
| JOI | Io + 3.8 h |
| PJR | JOI + ~100d |
| Begin Tour | PJR + ~100d |
| Begin "End Game" | + 12-15m |
| EOI | + 3m |
| End of Mission | EOI+30d |

* All dates and durations are current estimates.

Legend :

- Cruise Segment
- Ballistic Multiple Flyby Tour (using Ganymede, Callisto, and Europa).
- Mission Endpoint
- Maneuver
- Unpowered Flyby

Acronyms:

DSM: Deep Space Maneuver
JOI : Jupiter Orbit Insertion
PJR : Perijove Raise Maneuver
G1 : Ganymede 1 Flyby
EOI : Europa Orbit Insertion

Robert W. Maddock
3 April 1997

# Flight System Example

## for Europa Orbiter

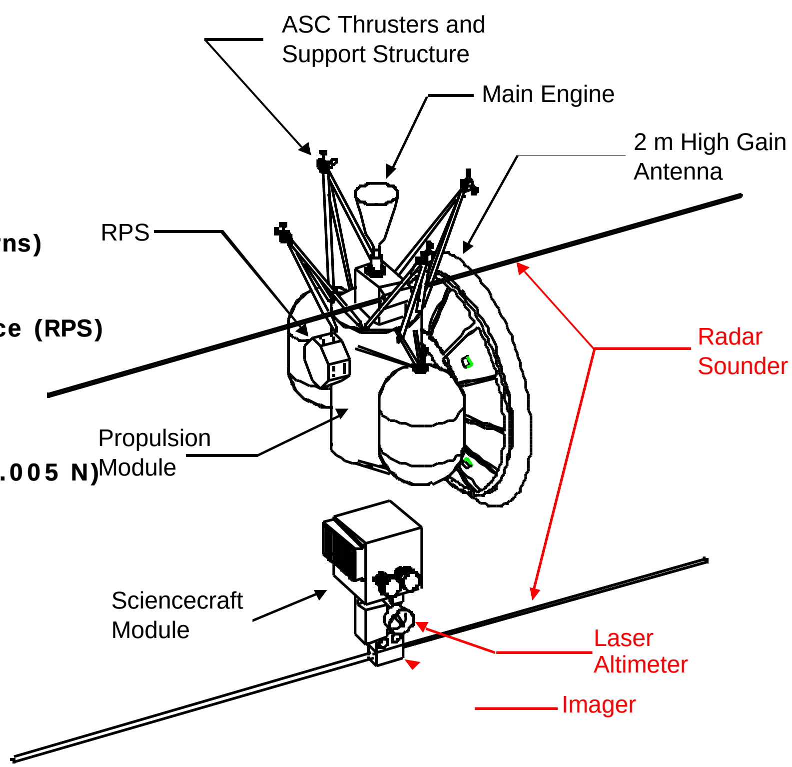
*X 2 0 0 0*

**Flight System Summary**

- o **Science**
  - **Mission specific**
  - **Sci. Data Processor (clone of eng. processor)**
- o **Structure**
  - **Composite & Modular**
- o **Telecom**
  - **Deep Space Tiny Transponder (DSTT)**
  - **Redundant X-band SSPA's**
  - **Single string Ka-band SSPA**
  - **HGA, LGA**
  - **Optical communication under study**
- o **Sciencecraft Data Subsystem**
  - **3D Stack MCM Computer**
  - **Stacked DRAM Solid State Recorder**
  - **Low power, high rate data bus**
  - **Low rate utility bus**
- o **Attitude Control**
  - **3 axis stabilized**
  - **Advanced miniature star tracker**
  - **Solid state IRU (for main engine burns)**
  - **Sun sensors**
- o **Power**
  - **Advanced Radioisotope Power Source (RPS)**
  - **Power switching microelectronics**
  - **Battery under study**
- o **Propulsion**
  - **Biprop with 400 N main engine**
  - **Miniature hydrazine RCS thrusters (.005 N)**
- o **Temperature Control**
  - **RPS waste heat**
  - **MLI blankets and louvers**
  - **Electrical heaters (to be minimized)**
- o **Electronic Packaging**
  - **Stacked MCM's**

**Performance**

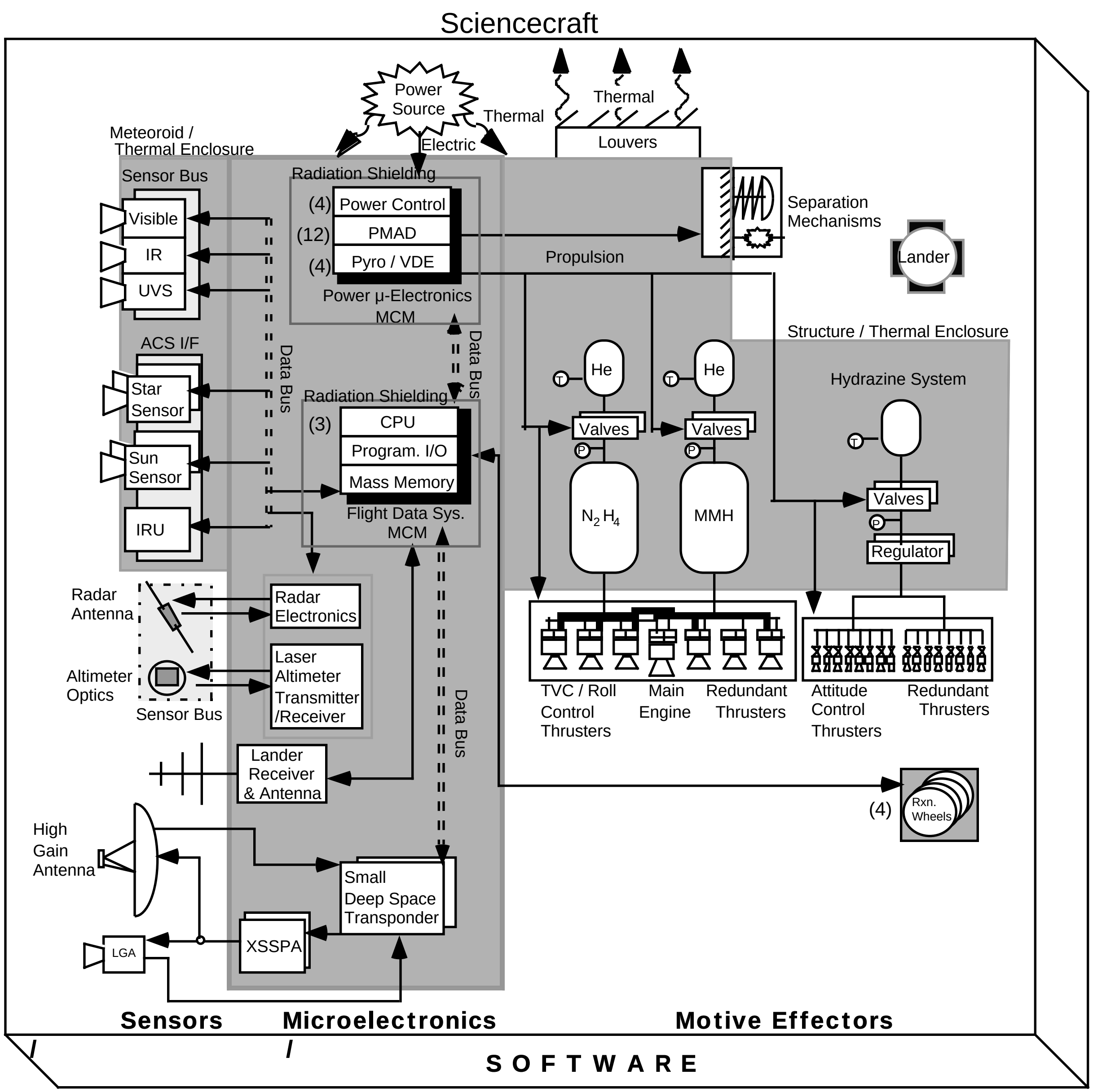
| | |
|---|---|
| **Pointing Control** | **2 mrad** |
| **Pointing Knowledge** | **1.5 mrad** |
| **Rate Control** | **<10 μrad/sec** |
| **Processor Speed** | **4-50 MIPS** |
| **Data Bus Rate** | **50 Mb/sec** |
| **Data Storage** | **Redundant 4 Gb** |
| **Downlink @Europa** | **~5 Kb/sec** |
| **Power** | **150 W @Europa** |
| **ΔV Capability** | **2.5 km/sec** |




| | Mass | Power |
|---|---|---|
| **TELECOMMUNICATIONS** | | |
| Antennas | 4.00 kg | |
| Transmitter & Receiver | 7.50 kg | 29.0 W |
| Waveguide/Switches/Misc. | 5.80 kg | |
| **POWER & PYRO** | | |
| Radioisotope Power Source | 9.00 kg | |
| Power Micro-elect. (DC-DC conversio | 5.80 kg | 23.0 W |
| **ATTITUDE CONTROL** | | |
| Star Sensors | 2.00 kg | 0.5 W |
| Inertial Reference Units | 0.40 kg | 4.0 W |
| Sun Sensors | 1.00 kg | 0.2 W |
| Sensor I/F Unit | 0.50 kg | 6.0 W |
| Valve Driver Electronics | 1.20 kg | 2.5 W |
| **DATA SUBSYSTEM** | | |
| Flight Computers and Memory | 3.20 kg | 13.0 W |
| Data Busses | 0.40 kg | 9.0 W |
| **STRUCTURE & CABLING** | | |
| Bus Structure | 4.00 kg | |
| HGA Support Structure | 1.20 kg | |
| Fittings & Brackets | 5.00 kg | |
| Separation Hardware | 5.50 kg | |
| Cabling | 5.00 kg | |
| **THERMAL CONTROL** | | 7.0 W |
| MLI Blankets | 2.00 kg | |
| Louvers | 0.80 kg | |
| Misc. | 1.70 kg | |
| **SCIENCE** | | |
| Multi-Spectral Instrument | 5.40 kg | 5.0 W |
| Radar Science | 5.00 kg | 10.0 W |
| Miscellaneous | 0.50 kg | |
| **Subtotal** | **76.90 kg** | **109.2 W** |
| **RADIATION SHIELDING** | 15.00 kg | |
| **PROPULSION MODULE** | | |
| Tanks | 24.10 kg | |
| Structure & Cabling | 30.30 kg | |
| Propulsion Components | 20.90 kg | |
| Thrusters | 10.00 kg | 6.0 W |
| MLI Blankets & RHU's | 11.40 kg | |
| 30% Contingency | 56.58 kg | 34.6 W |
| Propellants | 428.20 kg | |
| **ATTACHED PROBES** | | |
| Europa Lander | 15.00 kg | |
| **TOTAL WET MASS** | **688.4 kg** | **149.7 W** |

# Europa Orbiter Functional Element Layout





# OUTER PLANETS EXPLORATION PROGRAM

## PRIMARY PLUTO SCIENCE OBJECTIVES

Map the geology and surface processes on Pluto and Charon gl

Map the surface composition of geologic units globally on Pluto
Charon.

Characterize the main constituents, temperature/pressure prof
any hazes in Pluto's atmosphere.

## MEASUREMENT OBJECTIVES

Visible imaging globally at 1 km resolution.

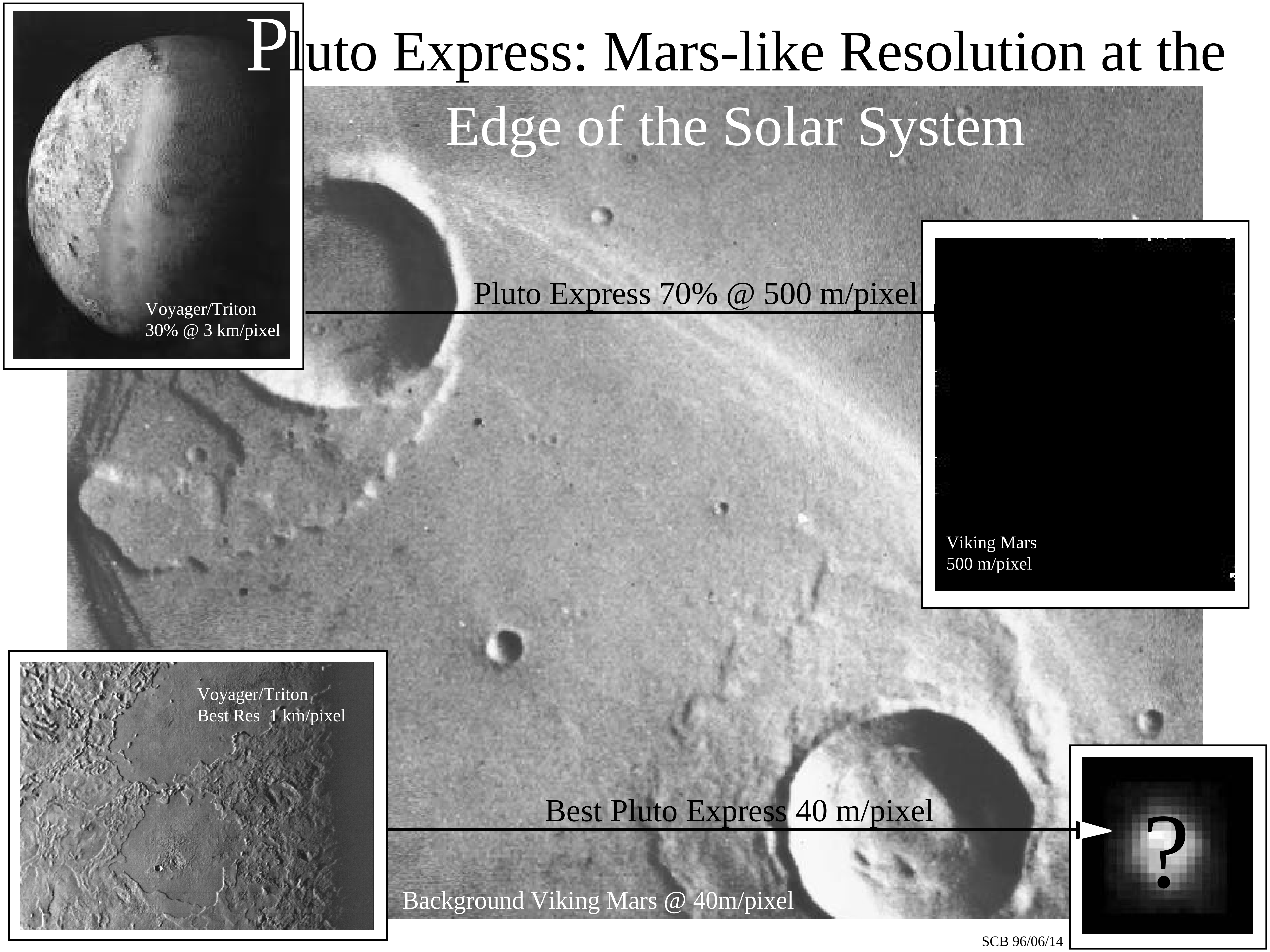
Near infrared imaging spectrometry:
- 5-10 km spatial resolution.
- 300-400 elements over ~1-2.5 μm to discriminate among ices
organic?

Ultraviolet occultation spectrometry.

Uplink X-band radio occultation.

Kuiper Disk object extended mission option with same instrumentation.

# Pluto Express: Mars-like Resolution at the Edge of the Solar System




SCB 96/06/14

# Pluto Mission Considerations



- Long Duration, Distance, and Radiation
  - ~9-11 year mission duration within capability of interplanetary spacecraft wit redundant components. Extended mission capability probable within actual fl margins.
  - Plan to upgrade flight software as ground-based capabilities increase; X2000 architecture is specifically focused on this capability.
  - RF telecom mutually compatible for Pluto and Europa (~100-500 bps downlinl Pluto, depending on DSN configuration).
  - Radiation during jovian flyby is tolerable, especially with X2000 common components driven by Europa requirements.
- Power
  - Requires ~100 $W_E$
  - 3 brick Radioisotope Power Source (RPS) would meet Europa rqmts. and provi needed Pluto power margins.
- Propulsion
  - Solar Electric + chemical, and all-chemical options available.
  - Hydrazine thrusters needed for trajectory correction maneuvers and attitude control.
- Avionics and Telecom
  - X2000 3D stack avionics and telecom should meet Europa, Pluto, and Solar Pı needs with a common, flexible, and upgradeable architecture and design.

# Flight System Example

## for Pluto Express

*X2000*

### Flight System Summary

- o Science
  - Mission specific
  - Sci. Data Processor (clone of eng. processor)
- o Structure
  - Composite & Modular
- o Telecom
  - Deep Space Tiny Transponder (DSTT)
  - Redundant X-band SSPA's
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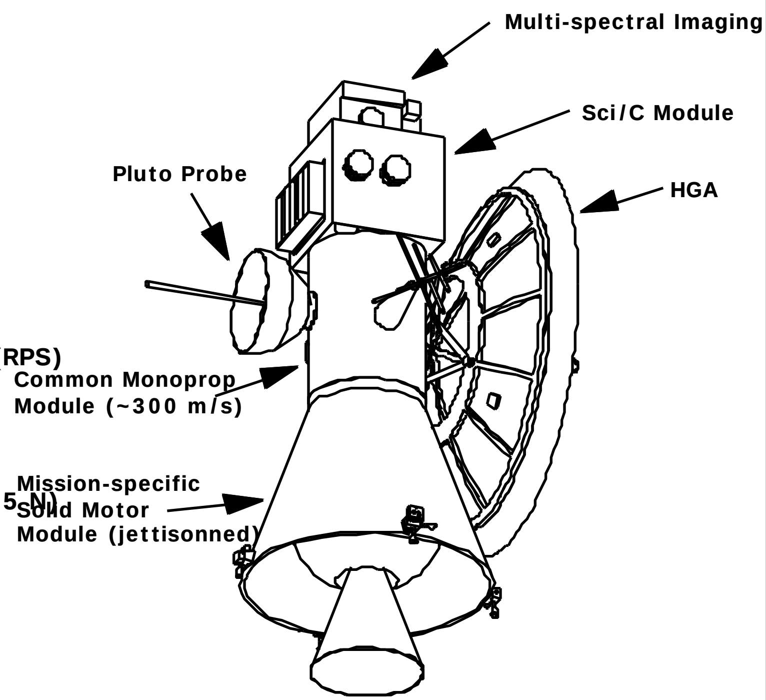
  - Low power, high rate data bus
  - Low rate utility bus
- o Attitude Control
  - 3 axis stabilized
  - Advanced miniature star tracker
  - Solid state IRU (for TCM burns)
  - Sun sensors
- o Power
  - Advanced Radioisotope Power Source (RPS)
  - Power switching microelectronics
  - Battery under study
- o Propulsion
  - All monoprop hydrazine
  - Miniature hydrazine RCS thrusters (.005 N)
- o Temperature Control
  - RPS waste heat
  - MLI blankets and louvers
  - Electrical heaters (to be minimized)
- o Electronic Packaging
  - Stacked MCM's

### Performance

| | |
|---|---|
| Pointing Control | 2 mrad |
| Pointing Knowledge | 1.5 mrad |
| Rate Control | <10 µrad/sec |
| Processor Speed | 4-50 MIPS |
| Data Bus Rate | 50 Mb/sec |
| Data Storage | Redundant 4 Gb |
| Downlink @Pluto | ~500 bits/sec |
| Power | 100 W @Pluto |
| ΔV Capability | ~300 m/sec |




Pluto Flyby '03, '04 Missions

| | Mass | Power |
|---|---|---|
| **TELECOMMUNICATIONS** | | |
| Antennas | 4.00 kg | |
| Transmitter & Receiver | 7.50 kg | 29.0 W |
| Waveguide/Switches/Misc. | 5.80 kg | |
| **POWER & PYRO** | | |
| Radioisotope Power Source | 6.50 kg | |
| Power Micro-elect. (DC-DC conversio | 5.80 kg | 15.0 W |
| **ATTITUDE CONTROL** | | |
| Star Sensors | 2.00 kg | 0.5 W |
| Inertial Reference Units | 0.40 kg | 4.0 W |
| Sun Sensors | 1.00 kg | 0.2 W |
| Sensor I/F Unit | 0.50 kg | 6.0 W |
| Valve Driver Electronics | 1.20 kg | 2.5 W |
| **DATA SUBSYSTEM** | | |
| Flight Computers and Memory | 3.20 kg | 10.0 W |
| Data Busses | 0.40 kg | 4.0 W |
| **STRUCTURE & CABLING** | | |
| Bus Structure | 4.00 kg | |
| HGA Support Structure | 1.20 kg | |
| Fittings & Brackets | 5.00 kg | |
| Separation Hardware | 5.50 kg | |
| Cabling | 5.00 kg | |
| **THERMAL CONTROL** | | 2.0 W |
| MLI Blankets | 2.00 kg | |
| Louvers | 0.80 kg | |
| Misc. | 1.70 kg | |
| **SCIENCE** | | |
| Multi-Spectral Instrument | 5.40 kg | 5.0 W |
| Miscellaneous | 0.50 kg | |
| **Subtotal** | **69.40 kg** | **78.2 W** |
| **RADIATION SHIELDING** | 5.00 kg | |
| **PROPULSION MODULE** | | |
| Tanks | 2.00 kg | |
| Structure & Cabling | 4.00 kg | |
| Propulsion Components | 2.00 kg | |
| Thrusters | 3.00 kg | 6.0 W |
| MLI Blankets & RHU's | 3.00 kg | |
| 30% Contingency | 26.52 kg | 25.3 W |
| Propellants | 10.00 kg | |
| **ATTACHED PROBES** | | |
| Pluto Probe | 15.00 kg | |
| **TOTAL WET MASS** | **139.9 kg** | **109.4 W** |

# “STRAWMAN” INTEGRATED SCIENCE PAYLOAD”

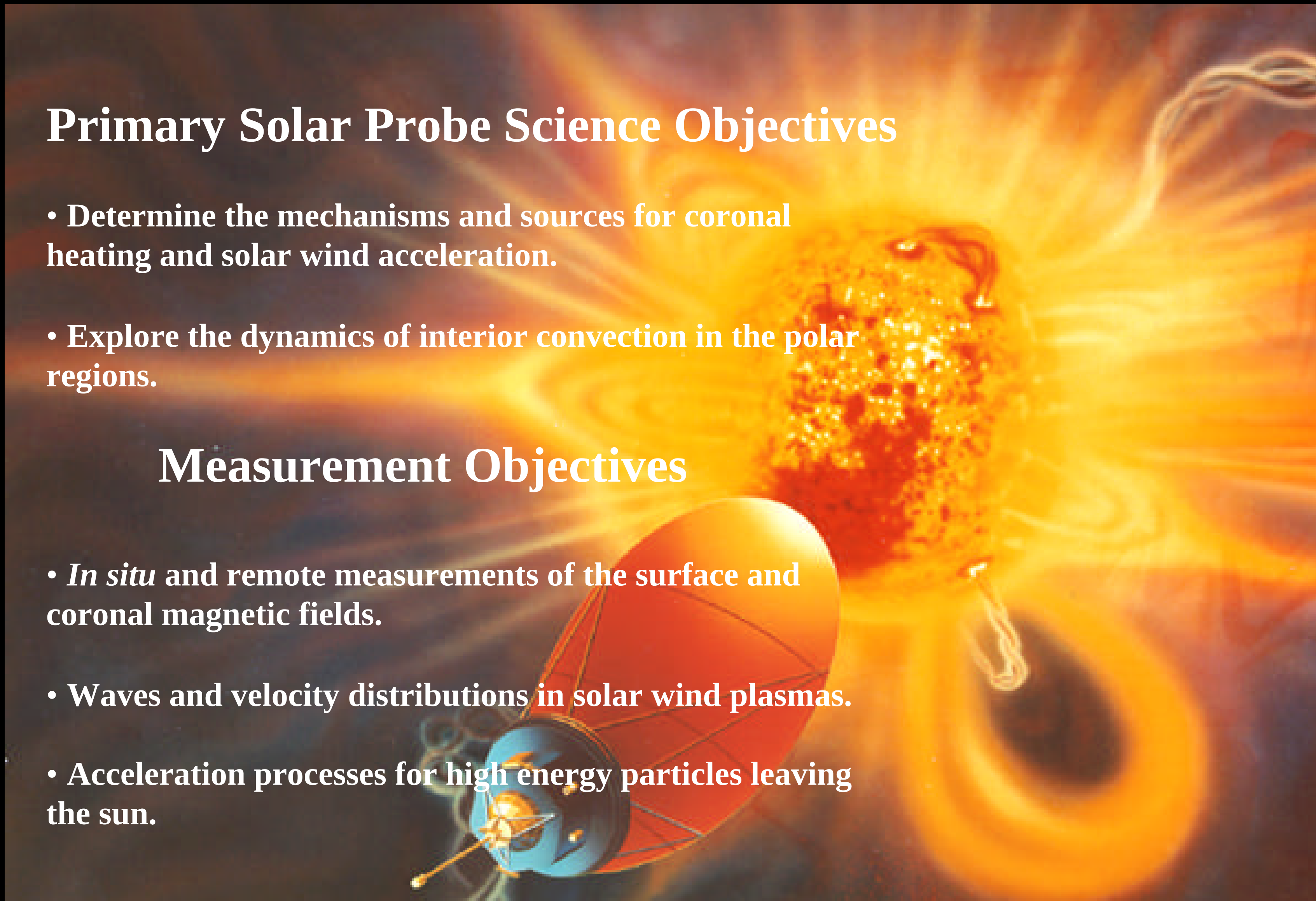
## INTEGRATED PAYLOAD - BOTH SPACECRAFT

- Visible CCD Camera
  - 750 mm focal length, 75 mm aperture
  - 1024x1024, 7.5µm pixel => 10 µrad resolution
- Infrared Spectrometer
  - Same fore optics as camera
  - 256x256, 40 µm pixel NICMOS HgCdTe Array
  - $\lambda/\Delta\lambda$ ~ 300 over 1.0 to 2.5 µm
- Ultra-Violet Spectrometer
  - Separate instrument EUV spectrometer
  - Wavelength range 55-200 nm
  - $\Delta\lambda$ = 0.5 nm
- Radio Science Uplink Occultation
  - Ultra-Stable Oscillator
  - incorporated into Telecom

RJT 10 July 1996

# OUTER PLANETS EXPLORATION PROGRAM





## Primary Solar Probe Science Objectives

• Determine the mechanisms and sources for coronal heating and solar wind acceleration.

• Explore the dynamics of interior convection in the polar regions.

## Measurement Objectives

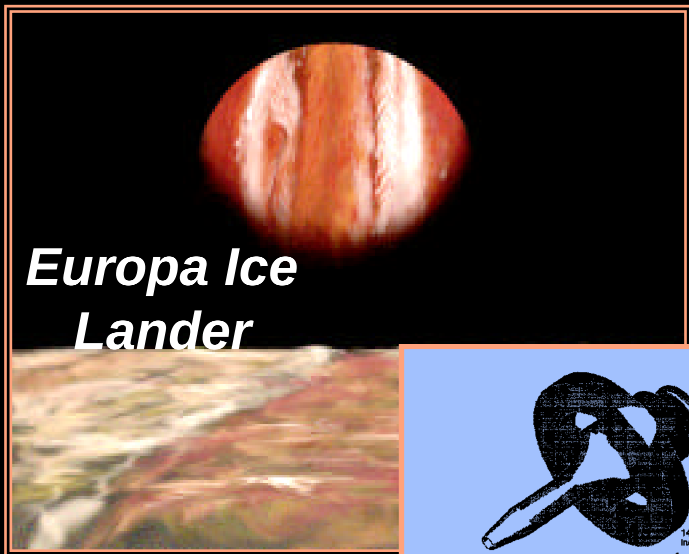
• *In situ* and remote measurements of the surface and coronal magnetic fields.

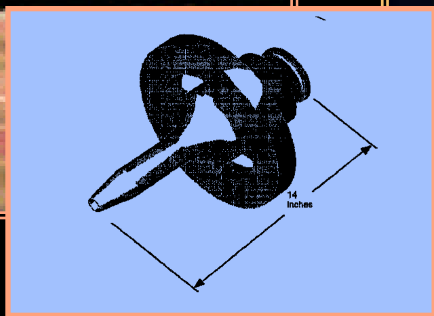
• Waves and velocity distributions in solar wind plasmas.

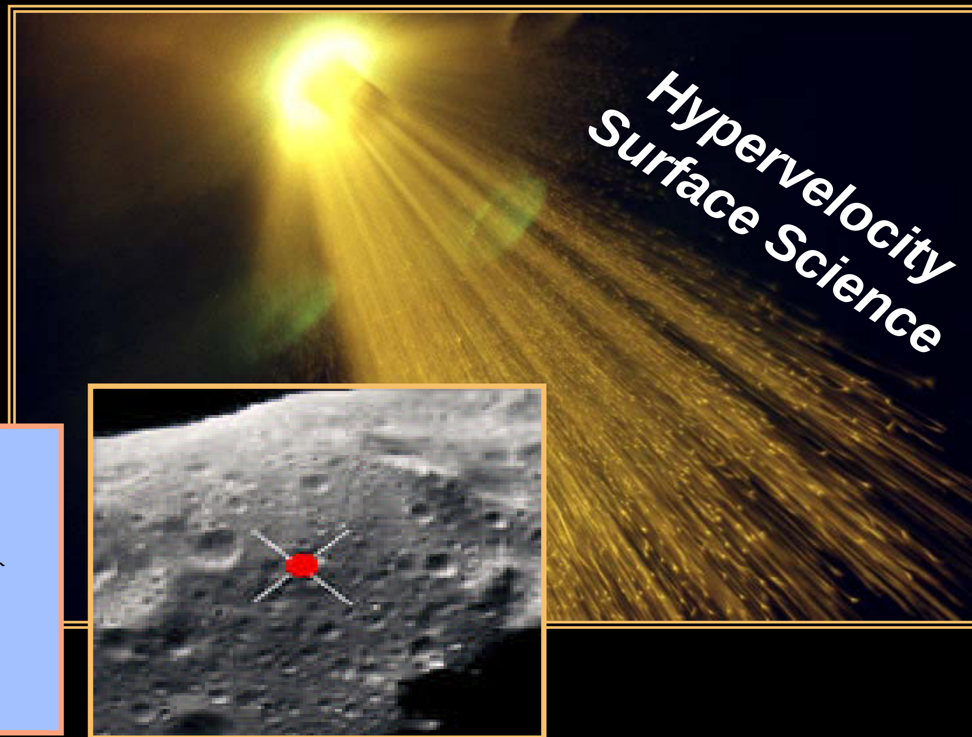
• Acceleration processes for high energy particles leaving the sun.

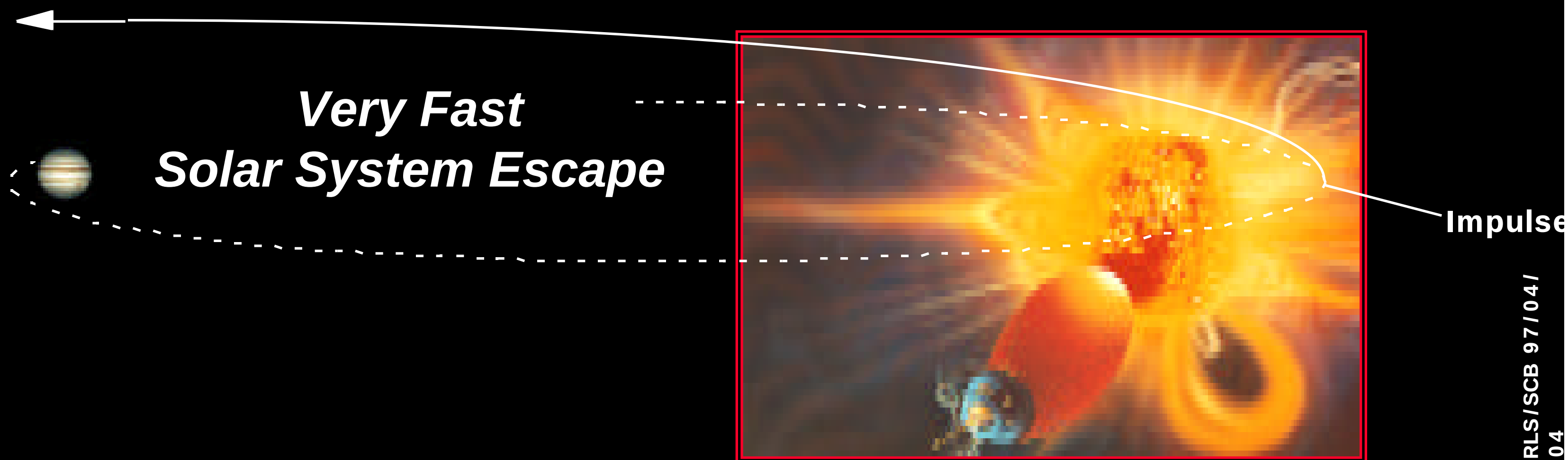
# Breakthrough Science and Technology:

## Sub-probe Opportunities for Outer Planets Missions



# Breakthrough Science/Technology Dividends
# Sub-Probe Opportunities for Outer Planet Missions

- o Each Outer Planet mission carries 15 kg mass allocation for a sub-probe and interface equipment.
  - not critical to parent mission success
  - funding source not specified

- o Concepts under consideration within JPL *In-Situ* Center of Excellence:

  <u>Europa</u>
  Mini-lander/Penetrator: measurement(s) useful for subsequent lander
  *prototype airless body mini-lander*
  Galilean Satellite Impactor: flash spectrometry *prototype for outer planet satellites*

  <u>Pluto</u>
  Drop Sonde: in-situ atmospheric measurements, impact flash
  *advanced US version of Russian-proposed Drop Zond*
  Skimmer: in-situ atmospheric measurements, magnetic field
  *precise navigation and longer duration, more data*
  Ballute (30 kg allocation): like Europa mini-lander/penetrator

  <u>Solar Probe</u>
  Heliopause/Interstellar Space Probe: far outer Solar System fields & particles
  *hypervelocity transit to deep outer Solar System, extreme communications challenge*
  Jupiter μProbe: deep atmospheric measurements *hypervelocity entry for deep probe*

  <u>Comet Nucleus Sample Return</u>
  Subsurface Explorer: depths beyond thermal wave to pristine material

- o Further concepts could be solicited competitively from science/industry/academia.

# “Europa Surface Package”--Tentative Concept and Goal

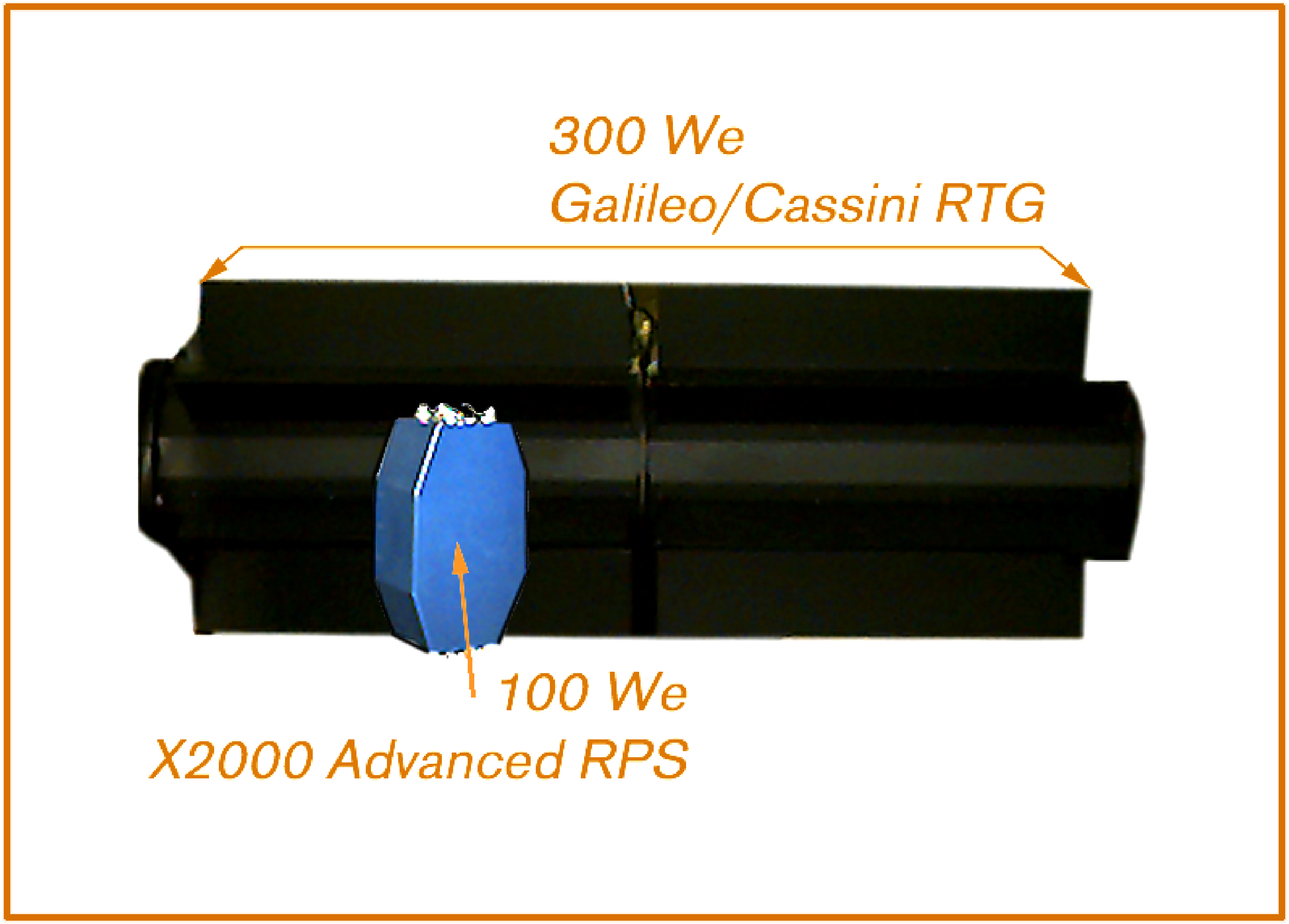
- Science or Technology “Dividends;” not critical to primary mission success.

- 15 kg Orbiter allocation for “Surface Package.” After separation mechanism and other Orbiter equipment (if any) to support Surface Package, net separated mass >10 kg.

- Options for impact velocity:
  - impact at ~orbital velocity (1.4 km/sec), observe plume
  - impact at penetrator velocity (Mars/Deep Space 2 100-200 m/s, atmosphere provides orientation)
  - landing at “airbag” velocity (Mars Pathfinder ~10 m/s)
  - “soft” propulsive landing (Viking ~2 m/s)

- Use Surface Package to provide some *in situ* information on surface conditions (e.g., seismicity, or texture, etc.) as precursor to guide design of highly capable landers to follow.

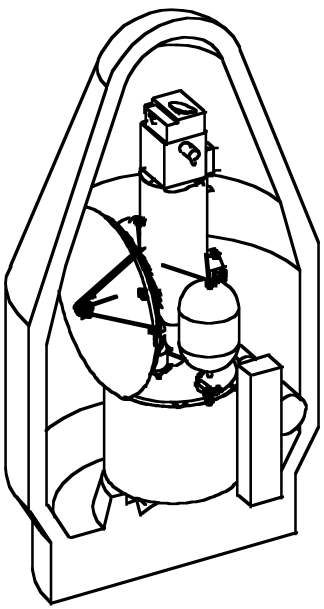
- Solicit best ideas within resources from science community.

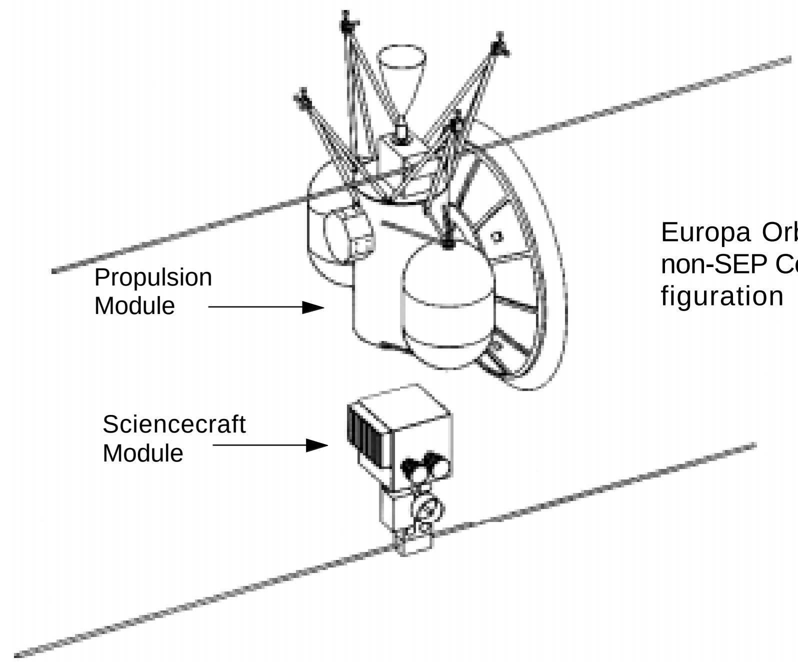

300 We
Galileo/Cassini RTG
100 We
X2000 Advanced RPS

# Solar Electric Propulsion (SEP) for Outer Planets

- SEP enables Comet Nucleus Sample Return (CNSR)
- Options being carried for Europa and Pluto; benefits and costs will continue to be weighed.
- Further term technology options will be considered for Solar Probe (e.g. more advanced SEP, solar sail).
- Continuing to explore tradeoffs

Europa Orbiter with SEP Module in Delta Fairing

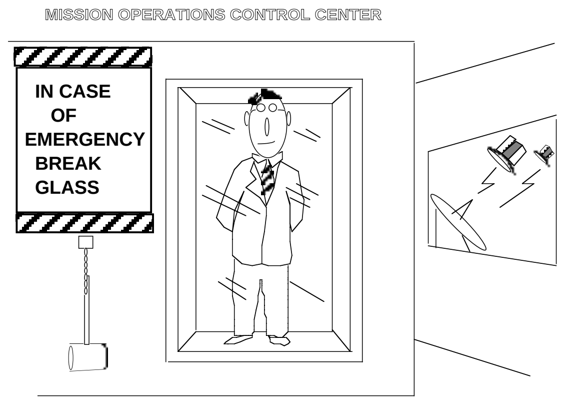


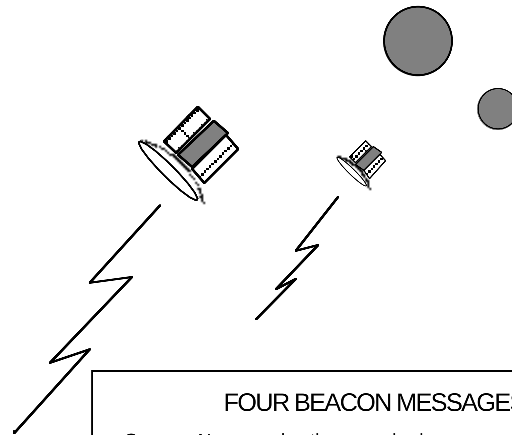


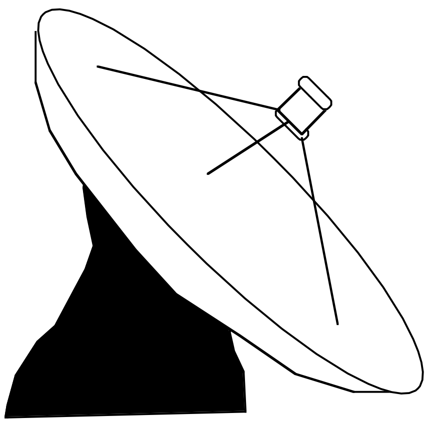

Europa Orbiter non-SEP Configuration

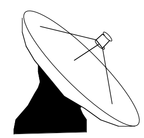
- There are many other missions for which SEP is enabling or enhancing.

# EUROPA / PLUTO / SOLAR PROBE BEACON MONITOR LINK







### FOUR BEACON MESSAGES:

Green - No ground actions required
(I'm OK)
Red - Schedule emergency telemetry track ASAP
(Call 911)
Orange - Schedule routine telemetry track within 1 week
(or I may lose data)
Yellow - Schedule a track whenever it's convenient
(I've got data that may be of near term interest)

## Traditional Telemetry Link

- 34 M DSN Station
- Complex Scheduling
- Complex Pointing
- Complex Pre & Post Cal
- Complex Receiving / Detection Equipment
  - Block V Rcvr
  - Symbol Synchronizer
  - Convolutional Decoder
  - Reed-Solomon Decoder
  - Frame Sync
  - Depacketization
- Complex Data Handling
  - GCF transmission
  - Data logging, QQC
  - Staging
  - Distribution
  - Decom
  - Display
  - Archiving

<u>SIMPLER FLIGHT SYSTEM</u> WITH OPERABILITY MARGINS, DESIGNED CONCURRENTLY FOR OPERATIONS

<u>SMART AUTONOMY</u> AND OPERATIONS SOFTWARE, DEVELOPED TO REDUCE OPERATIONS COSTS

<u>BUILT-IN BEACON TONE GENERATOR</u> (PART OF TRANSPONDER)

<u>SIMPLE TONE RECEIVERS</u> AT MULTIPLE SMALL-APERTURE SITES

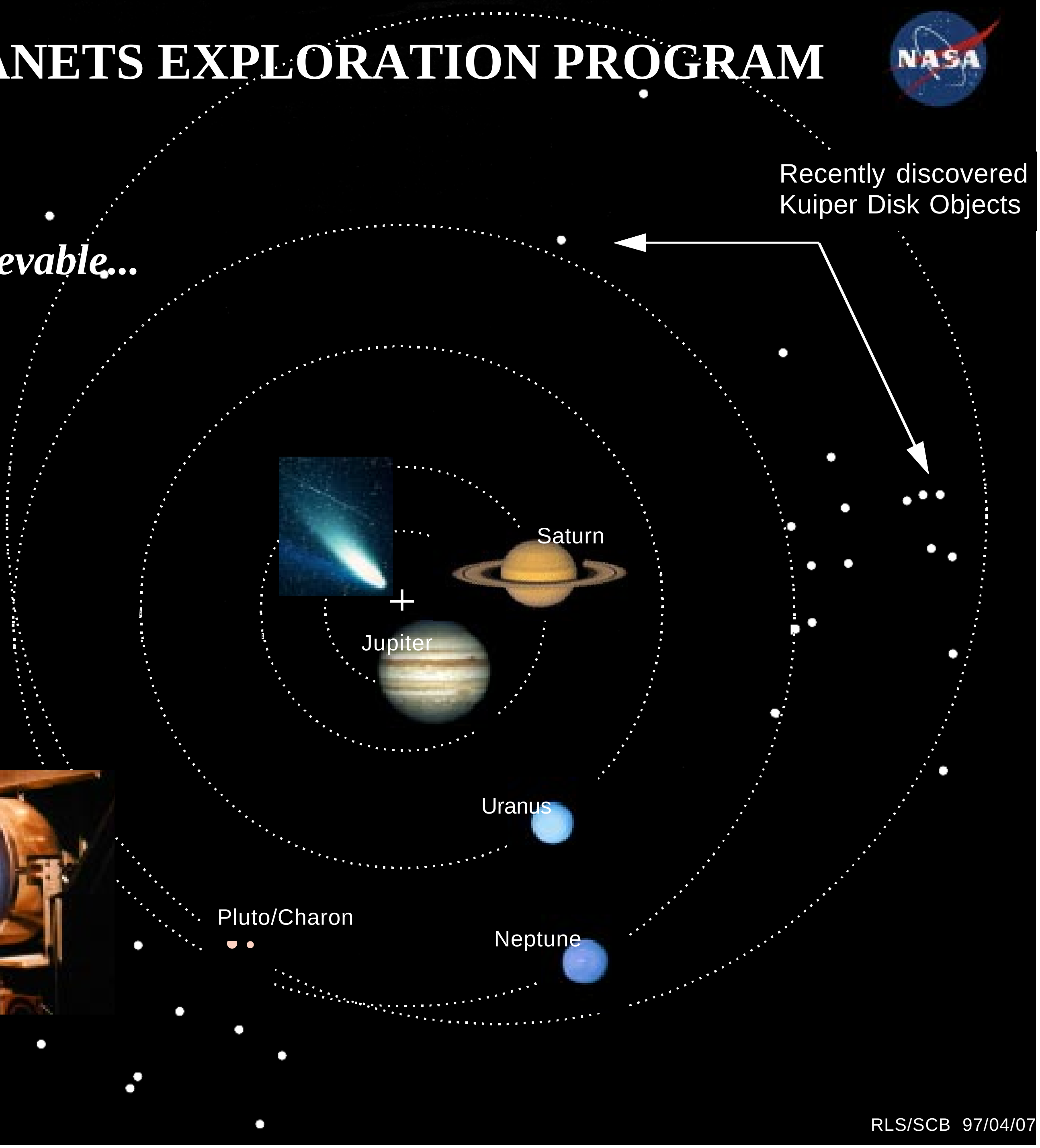
## Beacon Monitor Subcarrier Tone

- Much Smaller Ground Antenna
- Simple Scheduling
  - 15 mins per day anytime
- Simple Pointing (Wide Beamwidth)
- Simple Calibration
- Simple Receiving / Detection Equipment
  - Open Loop Receiver + Tone Detector
- Simple Message Handling
  - Bulletin Board on WWW
  - Auto Paging

Carraway
03/04/97

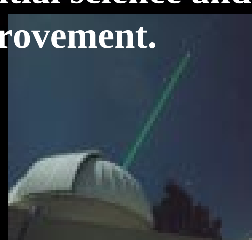
# OUTER PLANETS EXPLORATION PROGRAM

***Repeated access to the outer Solar System is achievable...***




**With X2000, Advanced Power, Center for Integrated Space Microsystems and other technology investments, individual outer Solar System mission costs are less than the Discovery cap.**

**Emerging technologies will continually be evaluated for potential science and cost improvement.**



# Outer Planet Program (OPP) Technology Requirements

| Technology Item | Project | | | | Color | | | Provider | Remarks |
|---|---|---|---|---|---|---|---|---|---|
| | E | P | S | C | R | Y | G | | |
| Adv. Radioisotope Power Source | E | P | | | | Y | | ARPS | |
| Long Life, Low Power mN Thruster | E | P | S | | R | | | Core | |
| High Isp Biprop Eng. (μ meteoroid resistant) | E | | | | | Y | | Core | enhancing |
| Advanced Biprop Components | E | | | C | R | | | Core | enhancing |
| Advanced Monoprop Components | E | P | S | | | Y | | Core | |
| High Density μ-Electronics Packaging | E | P | S | C | | | G | CISM/X2000 | |
| Power Mgmt. & Distribution (PMAD) | E | P | S | C | | | G | CISM/X2000 | |
| Power Converter MCM | E | P | S | C | | | G | CISM/X2000 | |
| Power Control MCM | E | P | S | C | | | G | CISM/X2000 | |
| Energy Storage MCM & Ultra-capacitor | E | P | | | | | G | CISM/X2000 | |
| Low Power Data Bus | E | P | S | C | | | G | CISM/X2000 | |
| Uplink & Downlink Interface | E | P | S | C | | | G | CISM/X2000 | |
| Adv. Field Progm. Gate Array (FPGA) | E | P | S | C | | | G | CISM/X2000 | |
| Rad Hard EEPROM | E | P | S | C | | | G | CISM/X2000 | |
| Rad. Hard A-to-D Converter | E | P | S | | | | | CISM/X2000 | |
| Advanced Star Tracker | E | P | S | C | | | G | CISM/X2000/DTU | |
| Medium Precision Micro Gyro | E | P | | | | Y | | Core | |
| Very High Precision Micro Gyro | | | S | | | Y | | X2000/Core | |
| Carbon-Carbon HGA/Shield Technology | E | P | S | C | R | | | Core | |
| High Temp. X-Band Feed System | | | S | | | Y | | Core | |
| Very High Temperature Solar Array | | | S | | R | | | Core | |
| Near-Sun Thermal to Electric Converter | | | S | | R | | | Core | |
| Low Mass Radiators, Thermal Shields | | | S | | | Y | | Core | |
| High Temp. Materials and Panels | | | S | | | Y | | Core | |
| Telecom with Plasma Scintillations | | | S | | | Y | | OPP | |
| Low Mass/Pwr. Radar Sounder | E | | | | | Y | | PIDDP/OPP/Core | |
| Multi-Spectral Science Instrument | E | P | | | | | | PIDDP/OPP/Core | |
| Integ. Fields & Particles Instrument | | | S | | | | G | OPP | |
| Advanced Fault Protection | E | P | S | C | | | G | Core/X2000/NMP | |
| On-Board Engineering Data Summation | E | P | S | C | | | G | Core/X2000/NMP | |
| On-Board Planning and Scheduling | E | P | S | C | | | G | Core/X2000/NMP | |
| Smart Executive | E | P | S | C | | | G | Core/X2000/NMP | |
| Navigation for comet approach/landing | | | | C | | Y | | OPP/Expl. Tech. | |
| Landing/anchoring | | | | C | | Y | | Core/Expl.Tech. | |
| Sample acquisition | | | | C | | Y | | Core/Expl.Tech. | |
| Sample return | | | | C | | Y | | Core/Expl.Tech. | |
| In-situ chemical analysis | | | | C | | Y | | Core/Expl.Tech. | |
| Adv. Microwave Control & Filtering | E | P | S | C | | | G | SOMO | |
| High Efficiency Ka-Band SSPA | E | P | S | | | | G | SOMO | |
| High Efficiency X-Band SSPA | E | P | S | | | Y | | SOMO | |
| Advanced Deep Space Transponder | E | P | S | | | | G | X2000 | |
| Precision Self-Pointing for Science | E | P | | C | | | G | X2000/Core | |
| On-Board Navigation | E | P | | C | | | G | X2000/OPP | |
| Small, Low Pwr. Precision Time Ref'nc. | | P | S | | | | G | SOMO/X2000 | |
| Low mass, high eff. 5 AU Solar Array | | | S | C | R | | | Core | |
| High Density Primary Power | | | S | C | | | G | Core | |
| High Density Secondary Batteries | | | S | | | | G | Core | |
| Advanced SEP | | | | C | | Y | | Core | |
| Smart Propulsion | E | | | | | | G | Core | |
| μ-3-Axis Seismometer | E | | | C | | | | Core | |
| Rad-Tolerent Detectors | E | | | | | | | Core | |
| Low m, p, Laser Altimeter | E | | | C | | | | Core/Code Y | |